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DYNAMIC PERFORMANCE ASSESSMENT OF SIDE FACING TROOP SEATS DURING IMPACT

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Final Report

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14. ABSTRACT The Aircrew Biodynamics and Protection Group of the Applied Neuroscience Branch (711 HPW/RHCPT) agreed to conduct a dynamic comparative test program of currently-fielded side facing troop seats. The test program consisted of impact testing of stock UH-60, CV-22, and CH-53 seats. The tests were conducted to compare how effectively the seats protected occupants ranging from the 5th percentile female to 98th percentile male. A series of ten tests using each type of seat was performed. Test orientations, manikins, and impact levels were based on MIL-S-85510(AS) as well as the impact levels at which currently-fielded H-60 troop seats were accepted for operational use.

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1.0 INTRODUCTION

A recent study of 917 Class A and B Department of Defense (DoD) helicopter mishaps indicated that occupants of helicopter cargo compartments have a significantly greater chance of being injured or killed during a mishap than occupants in the cockpit (Mapes et al., 2007). The study discovered that vascular injuries to the chest were the leading cause of fatality in Class A helicopter mishaps and that open skull fractures were the second. These two mechanisms of fatality were the most common compared to other causes such as injuries to the neck and the extremities. This may have been due, in part, to the aircraft being originally outfitted with stroking, crashworthy seating.

Based on these reports, the Aircrew Biodynamics and Protection Group of the Applied Neuroscience Branch (711 HPW/RHCPT) agreed to conduct a dynamic comparative test program of currently-fielded side facing troop seats. The test program consisted of impact testing of stock UH-60, CV-22, and CH-53 seats. The tests were conducted to compare how effectively the seats protected occupants ranging from the 5th percentile female to 98th percentile male. A series of ten tests using each type of seat was performed. Test orientations, manikins, and impact levels were based on MIL-S-85510(AS) as well as the impact levels at which currently-fielded H-60 troop seats were accepted for operational use.

Testing was conducted under a Memorandum of Agreement (MOA) with the Defense Safety Oversight Council (DSOC) and the Office of the Secretary of Defense, Deputy Director, Live Fire Test & Evaluation (OSD/DOT&E).

The comparative testing is experimental and not intended to qualify specific seats for acquisition. Consideration of the weight and cost of seats were beyond the scope of this research effort. Test conditions were chosen to show crashworthiness protection at different levels and orientations. The methodology that was developed for this effort allows seating to be tested independent of airframes and could be used for the basis of performance testing prior to acquisition decisions being finalized. Comparative testing that is not dependent upon specific airframes allows direct comparison of the crashworthy properties of various seats developed at different times and with different technologies. Seating between different aircraft can be directly compared and structural and energy attenuator technologies can be identified and shared among rotorcraft and fixed-wing platforms using the defined test methodology.

This testing focuses solely on the survivability of the seat and occupant biodynamics during primary impact. Secondary injury effects such as an occupant impacting other occupants, equipment, or aircraft structure were not considered in this study. Also, the ability of the occupant to egress the rotorcraft post-crash was not considered.

2.0 SUMMARY OF TECHNICAL APPROACH

A series of short-duration impact acceleration tests were conducted with a Lightest Occupant In Service (LOIS) manikin representing a 5th percentile female, and a Large Anthropomorphic Research Device (LARD) manikin representing a 98th percentile male. Both LOIS and LARD manikins are Hybrid III–type manikins that have been scaled to represent small and large occupants in the aerospace environment. The manikins were not loaded with combat equipment for these tests. The impact acceleration inputs to the seats were generated using the Horizontal Impulse Accelerator (HIA) and Vertical Deceleration Tower (VDT). The experimental conditions varied in seat orientation with fixed impact amplitudes and durations.

Measurements included sled and carriage accelerations and velocity, seat accelerations, and manikin head, lumbar, and torso accelerations, forces, and moments. A test fixture was designed and fabricated to mount the seats in various orientations during impact and was instrumented with load cells at all seat mounting points.

2.1 Test Matrix

Figure 1 depicts the coordinate system used during all seat orientations and for data collection.

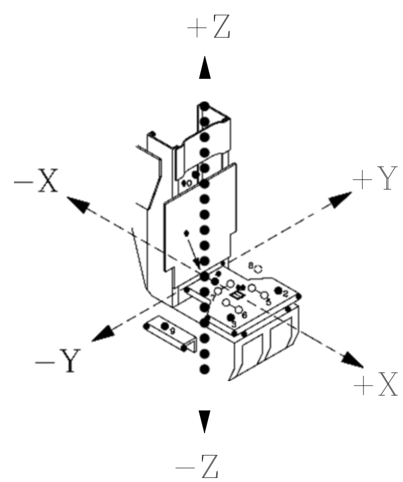

Figure 1. Coordinate System

The troop seats were tested in three different orientations; combined horizontal, pure vertical, and combined vertical.

The combined horizontal test configuration consisted of a yaw of 30 degrees relative to the x-axis acceleration pulse. This orientation is shown in Figure 2 below.

Figure 2. Combined Horizontal

The pure vertical test configuration had no offset relative to the positive z-axis. This orientation is shown in Figure 3 below.

Figure 3. Pure Vertical

The combined vertical test configuration consisted of a 30 degree pitch and 10 degree roll relative to the acceleration pulse. This orientation is shown in Figure 4 below.

Figure 4. Combined Vertical

Testing configurations were based on MIL-S-85510(AS) and previous testing of the legacy H-60A/L troop seat (Sikorsky Document SER-70102). It should be noted that the rise times for the CV and PV tests are roughly half of what is required to meet MIL-S-85510(AS). The experimental test matrix is summarized in Table 1.

Table 1. Test Matrix

Cell	Orientation	Acceleration (G)	Delta V (ft/s)	Rise Time (ms)	Manikin
A	CV	24	40	30	LOIS
B	CV	30	48	26	LOIS
C	CV	24	40	30	LARD
D	CV	30	48	25	LARD
E	CH	18	46	78	LARD
F	CH	24	53	62	LARD
G	PV	15	32	35	LOIS
H	PV	34	46	26	LOIS
I	PV	15	32	35	LARD
J	PV	34	46	26	LARD

2.2 FACILITIES AND EQUIPMENT

The 711HPW/RHCP HIA was used for all Combined Horizontal testing. The HIA consists of a 4ft by 8ft sled positioned on a 204ft track and is accelerated using a 24-inch diameter pneumatic actuator. The HIA operates on the principle of differential gas pressures acting on both surfaces of a thrust piston in a closed cylinder. The impact acceleration occurs at the beginning of the experiment as stored high-pressure air is allowed to impinge the surface of the thrust piston, thus propelling the sled. As the sled breaks contact with the thrust piston, the sled coasts to a stop or is stopped with a triggered pneumatic brake system. The impact acceleration is roughly sinusoidal. Metering pin 52 was used for all cells.

The 711HPW/RHCP VDT was used for all Combined Vertical and Pure Vertical tests. The VDT is a 40ft gravity-assisted tower primarily used for simulation of the catapult phase of ejection. The VDT facility is composed of two vertical rails and a drop carriage. The carriage is allowed to enter a free-fall state that is guided by the rails from a pre-determined drop height. A plunger mounted on the rear of the carriage is guided into a cylinder filled with water located at the base and between the vertical rails. A deceleration pulse is produced when water is displaced from the cylinder by the carriage-mounted plunger. The pulse shape is also roughly sinusoidal and is controlled by varying the drop height, which determines the peak G-level, and by varying the shape of the plunger, which determines the rise time and duration of the pulse. Metering pin 104 was used for all cells.

MIL-S-85510(AS) requires deformation of the seat mount locations to simulate deformation of an airframe during a crash event. For these comparison tests, it was determined that deformation of mounting points was not necessary.

2.3 SUBJECTS

A LOIS manikin, representing a 5th percentile female (by weight and height), was used for testing. LOIS is a Hybrid III-variant manikin with a straight spine. LOIS is currently used by the Air Force and Joint Strike Fighter (JSF) during ejection seat sled testing. LOIS was dressed in a flight suit and a medium Advanced Combat Helmet (ACH) for a total weight of 107.5lbs. LOIS weight distribution is shown in Table 2.

Table 2. LOIS Manikin

Body Segment	Weight
Upper Torso	48.5
Manikin	45.3
Instrumentation	1.8
Cables	1.4
Lower Torso	59
Manikin w/abdomen	47
Instrumentation	1.4
AFE	10.6
Total	107.5

A LARD manikin, representing a 98th percentile male (by weight and height), was also used for testing. LARD is a Hybrid III-variant manikin with a straight spine. LARD is also used by the Air Force and JSF in ejection seat sled testing. LARD was dressed in a flight suit and a large ACH helmet for a total weight of 247.8lbs. LARD weight distribution is shown in Table 3.

Table 3. LARD Manikin

Body Segment	Weight
Upper Torso	112.2
Manikin	108.8
Instrumentation	1.6
Cables	1.8
Lower Torso	135.6
Manikin w/abdomen	118.6
Instrumentation	1.4
AFE	15.6
Total	247.8

2.4 SEATS

There were three operational seats tested in this program:

(1) H-60 legacy seat currently installed in Army, Navy, and Air Force H-60 rotorcraft
(2) CV-22 seat currently installed in Air Force CV-22 rotorcraft
(3) CH-53 seat currently installed in Navy H-53 rotorcraft

2.5 DATA

Data were collected at 1,000 samples per second and filtered on-board the Data Acquisition System (DAS) using an 8-pole Butterworth filter at 120Hz. The filtering chosen has been demonstrated to be adequate for this type of comparison test program but is not necessarily consistent with filtering used during qualification testing. Table 4 lists the data channels collected. High-speed video of the test was taken at 1000 frames per second.

Table 4. Data Channels

Carriage X, Y, and Z Acceleration (G)
Seat Fixture X, Y, and Z Acceleration (G)
Seat Pan X, Y, and Z Acceleration (G)
Top Left Seat Mount X, Y, and Z Force (LB)
Top Right Seat Mount X, Y, and Z Force (LB)
Bottom Left Front Seat Mount X, Y, and Z Force (LB)
Bottom Right Front Seat Mount X, Y, and Z Force (LB)
Bottom Left Rear Seat Mount X, Y, and Z Force (LB)
Bottom Right Rear Seat Mount X, Y, and Z Force (LB)
Left Torso Restraint Force (LB)
Right Torso Restraint Force (LB)
Left Lap Restraint Force (LB)
Right Lap Restraint Force (LB)

Internal Head X, Y, and Z Acceleration (G)
Internal Head Y Angular Acceleration (Radians/Sec^2)
Internal Upper Neck X, Y, and Z Force (LB)
Internal Upper Neck Moment X, Y, and Z Torque (IN-LB)
Internal Lower Neck X, Y, and Z Force (LB)
Internal Lower Neck Moment X, Y, and Z (IN-LB)
Internal Chest X, Y, and Z Acceleration (G)
Internal Chest Y Angular Acceleration (RAD/SEC^2)
Internal Lumbar X, Y, and Z Acceleration (G)
Internal Lumbar X, Y, and Z Force (LB)
Internal Lumbar Moment X, Y, and Z Torque (IN-LB)

2.6 TEST PROCEDURE

Data channels were zeroed prior to the manikin being placed into the seat. The manikin was then placed into the seat and restraint belts were pre-tensioned to 20lbs +/- 5lb. The helmet was placed on the manikin head and secured as tight as possible to prevent slippage. On the VDT the carriage was raised to a pre-determined height to provide the required acceleration and velocity profile and then dropped. On the HIA the cylinder was pumped up to pre-determined pressures to match the desired acceleration and velocity profile. Prior to the manikin being removed from the seat, the restraint buckle release loads were recorded.

2.7 INJURY CRITERIA

The injury probability metrics used were primarily taken from the Full Spectrum Crashworthiness (FSC) report (Bolukbasi et al., 2011**)** as it incorporates the most recent recommended troop seating injury criteria for the head, neck, chest, lumbar spine, and extremities. Not all criteria from the FSC report were used as they were not applicable to the test setup. For instance the Head Injury Criterion (HIC) was not used because no aircraft structure was simulated during testing other than the single seat itself. Reporting of head-strike data could be misleading and irrelevant given the experimental setup for this test series.

For neck injury probability, Nij was used as it is the most accepted and validated criteria in the X-Z plane. Nij combines tension (t), compression (c), flexion (f), and extension (e) of the upper neck to determine a probability of injury at a given injury level and is part of the JSF Neck Injury Criteria (NIC) (Nichols, 2006). Though primarily developed and used in automotive environments, Nij thresholds have been modified for military personnel in aircraft environments for different occupant sizes. A Nij value of 0.5 correlates to a 10% probability of an Abbreviated Injury Scale (AIS) ≥2 neck injury. For instance a Ntf value (Ntf is the Nij value in tension-flexion) of 0.5 is a 10% probability of an AIS ≥2 neck injury in tension-flexion. Nte is the Nij value in tension-extension, Ncf is compression-flexion, and Nce is compression-extension. Nij can be calculated for both upper and lower neck locations. Only upper neck Nij values are reported for this program.

A limitation of Nij is that it was developed primarily for +/-X accelerations and does not report off-axis injury probability. The Upper Neck Moment Index X (UNMIx) and Upper Neck Moment Index Z (UNMIz) were developed by the Navy to look at off-axis neck injury probability (Nichols, 2006). These criteria are part of the JSF NIC and use both linear force and neck moments, just like Nij, to determine a neck injury probability. As a guideline an UNMIx or UNMIz value of 0.5 correlates to a 10% probability of an AIS ≥2 neck injury. Validation of the criteria has been limited; however, the UNMIx and UNMIz are reported in this study for comparison.

For chest injury both chest acceleration and belt forces were collected during testing. The FSC Report recommends restraint belt force for injury probability. The criteria states that for one torso belt, the peak force must be less than 1750lb, and, for more than one torso restraint belt, the total peak force must be below 2000lb. All seats tested during this program utilized multi-point restraints, thus the 2000lb limit of the torso restraint belts is most applicable.

A chest resultant acceleration limit of 60G (Mertz, 1989) for manikins is discussed within the FSC, though the FSC does not recommend its use. The FSC recommends use of the torso belt peak loads instead. The reason for this is that the torso belt loads and the chest resultant acceleration criteria should show similar results in some orientations. Both torso belt restraint loads and chest acceleration are reported.

Lumbar injury probability is compared to limits derived by Desjardins (2008). The Desjardins lumbar force limits are based on 19.9 times the weight of a manikin above the lumbar load cell. For a standard LOIS manikin this correlates to a 933lb compression limit. For a 95% percentile Hybrid III male this correlates to a 1755lb compression limit. For the specific manikins used in this test program, the limits are 965lbs for the LOIS (based on manikin and instrumentation weight above the lumbar load cell equal to 48.5lbs) and 2232lbs for the LARD (based on manikin and instrumentation weight above the lumbar load cell equal to 112.2lbs).

Another criterion discussed but not recommended in the FSC to determine lumbar injury probability is the Dynamic Response Index (DRI). DRI was developed primarily for ejection seat lumbar injury probability and consists of a spring-damper model of the spine. DRI is not recommended in FSC as it is most useful for rigid, non-stroking seats with longer impact rise times and applicability to troop seats is questionable (Pellettiere, 2011; Desjardins, 2008). DRI_Z Dynamic Response Index in the vertical (Z) direction, is reported for the CV and PV orientations for comparison only.

A whole-body injury criterion discussed in the FSC is Eiband that was developed in the late 1950s. The Eiband criterion predates specific body-region injury criteria for seats (Eiband, 1958). Based on a literature review, Eiband developed acceleration-duration curves for each body-axis providing a no injury/moderate injury/severe injury rating system. The limitation of this work is that a nominal trapezoidal pulse is used. Pulses from the VDT and HIA are nominally half-sinusoidal instead of trapezoidal, thus relevancy of the use of the Eiband criteria is questionable at best. The use of Eiband is also questionable given the 60+ years of specific body-region injury work that has been accomplished since the Eiband criteria was published. In some cases, more recently developed neck, chest, and lumbar criteria are inconsistent with the results of Eiband. For this reason, Eiband values are not included in this report.

All criteria are not applicable for every orientation tested. The Pure Vertical orientation is primarily used for injury probability calculation while Combined Horizontal is used to determine structural integrity of the seat. Belt forces in the Combined Horizontal orientation can be used to determine chest injury probability. Combined Vertical is a mixture of both structural testing and injury probability calculation.

For this effort Nij, peak lumbar force, peak chest acceleration resultant, DRZ, and restraint belt forces are reported for the Pure Vertical orientation. Peak chest acceleration resultant and torso restraint belt forces are reported for the Combined Horizontal orientation. UNMIx and UNMIz, Nij, peak chest acceleration resultant, restraint belt forces, and peak lumbar Z force are reported for the Combined Vertical orientation tests. A summary of the criteria used is in Table 5.

Table 5. Injury Criteria Used

Area	Recommended by FSC	Criteria Used	CV	PV	CH
Head	HIC	None			
Neck	Nij	Nij	X	X	X
Chest	Belt Loads	Chest Accel and Belt Loads	X	X	
Lumbar	Peak Loads	Peak Loads and DRIz	X	X	

3.0 TEST PERFORMED

Tests performed in each cell are shown in Table 6 and are indicated by test facility ID (either HIA or VDT, and the test number specific to that facility). Not all cells were completed for each seat due to structural failures shown at lower levels. Cells where the seat was not tested are shown with an X.

Table 6. Tests Performed

Cell	H-60	CV-22	CH-53
A	VDT6593	VDT6585	VDT6589
B	VDT6594	VDT6586	VDT6590
C	VDT6595	VDT6587	VDT6591
D	VDT6596	VDT6588	VDT6592
E	HIA8966/8967	HIA8968	HIA8970
F	x	HIA8969	HIA8971
G	VDT6571	VDT6579	VDT6575
H	VDT6572	VDT6580	VDT6576
I	VDT6573	VDT6581	VDT6577
J	VDT6574	VDT6582	VDT6578

3.1 TEST-BY-TEST DESCRIPTION

A structural failure in this study was one where the seat did not adequately hold the occupant in the seat after the pulse. Cable breaks, fabric rips, and seat mount point detaching from mounting points are reported, though many of these are not considered as complete structural failures of the seat. It is realized that this is counter to qualification testing of seats.
Pictures from individual tests are located in Appendix E.

HIA8966- Cell E, CH, Legacy H-60, LARD, 18.26 G, 47.19 ft/s, 73 ms rise time
HIA8966 was the first CH test with the Legacy H-60 seat. The manikin was separated from seat fixture due to torn and detached shoulder restraints. Seat did stroke at both top mount points and the rear seat leg. All electronic data channels were present and continuous allowing data to be successfully collected. Torso belt force exceeded accepted limit, reaching 2891 lbs during impact. After impact the restraint buckle released with 22 lbs of force.

HIA8967- Cell E, CH, Legacy H-60, LARD, 18.05 G, 46.93 ft/s, 76 ms rise time
HIA8967 was the second Cell E test. The manikin was separated from seat fixture due to torn and detached shoulder restraints. Seat did stroke at both top mount points and the rear seat leg. All electronic data channels were present and continuous allowing data to be successfully collected. After impact the restraint buckle released with 24 lbs of force.

HIA8968- Cell E1, CH, CV-22, LARD, 17.49 G, 46.21 ft/s, 69 ms rise time
HIA8968 was the first CH test with the CV-22 seat. The manikin remained in seat fixture despite some minor tearing on the lap belt. Torso belt force exceeded accepted limit, reaching 5851 lbs during impact. All electronic data channels were present and continuous allowing data to be successfully collected. After impact the restraint buckle released with 16 lbs of force.

HIA8969- Cell F1, CH, CV-22, LARD, 24.36 G, 53.02 ft/s, 62.3 ms rise time
HIA8969 was the first CH impact test at the higher energy level. The manikin remained in the seat fixture; however, the seat fixture failed at both mounts and became detached from the sled and test structure. Torso belt force exceeded accepted limit, reaching 5257 lbs during impact. All electronic data channels were present and continuous allowing data to be successfully collected. Neck moment index X (UNMIx) also exceeded the accepted limit, reaching 1.0243 during impact. After impact the restraint buckle released with 16 lbs of force.

HIA8970- Cell E2, CH, CH-53, LARD, 17.06 G, 46.14 ft/s, 73.8 ms rise time
HIA8970 was the first CH test with the CH-53 seat. No structural damage occurred during this test. Torso belt force exceeded accepted limit, reaching 4989 lbs during impact. All electronic data channels were present and continuous allowing data to be successfully collected. Neck moment index X (UNMIx) also exceeded the accepted limit, reaching 1.2657 during impact. After impact the restraint buckle released with 21 lbs of force.

HIA8971- Cell F2, CH, CH-53, LARD, 23.7 G, 52.63 ft/s, 57.7 ms rise time
HIA8971 was the second CH test with the CH-53 seat, but at a higher energy level. The seat fixture did show extensive damage, including complete fracture of both stroking rods causing the manikin to become partially dislodged from the seat in a hunched position. Torso belt force exceeded accepted limit, reaching 5644 lbs during impact. Neck moment index X also exceeded the accepted limit, reaching 0.9310 during impact. After impact the restraint buckle released with 35 lbs of force.

VDT6571- Cell G, PV, Legacy H-60, LOIS, 14.95 G, 31.2 ft/s, 55.4 ms rise time
VDT6571 was the first PV impact test performed, and also the first test using the LOIS manikin. The seat did slightly stroke at both top mount points. No structural damage was recorded for this test. All electronic data channels were present and continuous allowing data to be successfully collected. After impact the restraint buckle released with 26 lbs of force.

VDT6572- Cell H, PV, Legacy H-60, LOIS, 33.8 G, 48.87 ft/s, 57 ms rise time
VDT6572 was the first PV impact test at the higher energy level. Upon impact, significant amount of tearing to the seat pan occurred, causing the manikin to collapse through the seat pan. The seat did stroke at both top mount points. Stroking did not occur at the seat legs; however, there was separation where the front leg mounts to the floor of the test structure. Peak lumbar Z exceeded accepted limit, reaching 1353 lbs during impact. After impact the restraint buckle released with 15 lbs of force.

VDT6573- Cell I, PV, Legacy H-60, LARD, 15.42 G, 31.72 ft/s, 36.6 ms rise time
VDT6573 was the first PV impact test performed with the Legacy H-60 while using the LARD manikin on the VDT. The seat did stroke at both top mounting points. All electronic data channels were present and continuous allowing data to be successfully collected. After impact the restraint buckle released with 18 lbs of force.

VDT6574- Cell J, PV, Legacy H-60, LARD, 35.43 G, 48.94 ft/s, 33.2 ms rise time
VDT6574 was the second PV test with the Legacy H-60 and the LARD manikin, but at a higher energy level. The seat fixture did show extensive damage, including fracture of the front seat leg and a significant amount of tearing to the seat pan, causing the manikin to collapse through the seat pan. UNMIx exceeded the accepted limit, reaching 0.7510 during impact. After impact the restraint buckle released with 25 lbs of force.

VDT6575- Cell G2, PV, CH-53, LOIS, 14.82 G, 31.16 ft/s, 24.9 ms rise time
VDT6575 was the first PV impact test performed with the CH-53. Overall the seat showed no structural damage; however, the stroking mechanism material may have slightly been displaced, indicating seat stroke had occurred. Peak lumbar Z exceeded accepted limit, reaching 1368 lbs during impact. After impact the restraint buckle released with 7 lbs of force.

VDT6576- Cell H2, PV, CH-53, LOIS, 32.55 G, 48.97 ft/s, 19.1 ms rise time
VDT6576 was the second PV test with the CH-53 seat; however, this test was conducted at a higher energy level. Similar to the previous test, the CH-53 seat displayed no structural damage. The stroking mechanism material for this test was also slightly displaced, and the documented high-speed video files for this test clarified stroke had occurred. Peak lumbar Z exceeded accepted limit, reaching 2160 lbs during impact. After impact the restraint buckle released with 13 lbs of force.

VDT6577- Cell I2, PV, CH-53, LARD, 14.34 G, 31.39 ft/s, 27.5 ms rise time
VDT6577 was a repeat of test VDT6575, with the exception of the subject substitution of the LARD manikin. Overall the seat showed no structural damage; however, the stroking mechanism material had been displaced, due to seat stroke upon impact. All electronic data channels were present and continuous allowing data to be successfully collected. After impact the restraint buckle released with 8 lbs of force.

VDT6578- Cell J2, PV, CH-53, LARD, 34.8 G, 48.94 ft/s, 19.1 ms rise time
VDT6578 repeated the conditions of the previous test at a higher energy level. The seat exhibited minimal structural damage; however, there was some minor denting the upper region of the seatback and the stroking mechanism material had been displaced, due to seat stroke upon impact. All electronic data channels were present and continuous allowing data to be successfully collected. After impact the restraint buckle released with 9 lbs of force.

VDT6579- Cell G1, PV, CV-22, LOIS, 14.71 G, 31.2 ft/s, 28.1 ms rise time
VDT6579 was the first PV impact test performed with the CV-22. Overall the seat showed no structural damage. The stroking mechanism appeared to be slightly loosened at the bottom connection point during post-test inspection; however, no stroke occurred during impact. Peak lumbar Z exceeded accepted limit, reaching 1102 lbs during impact. After impact the restraint buckle released with 13 lbs of force.

VDT6580- Cell H1, PV, CV-22, LOIS, 33.65 G, 48.99 ft/s, 17.8 ms rise time
VDT6580 was the second PV test with the CV-22 seat; however, this test was conducted at a higher energy level. Similar to the previous test, the stroking mechanism appeared to be slightly loosened at the bottom connection point during post-test inspection. Displacement of the

stroking mechanism and post-test examination of the documented high-speed video files verified stroke had occurred during impact. Peak lumbar Z exceeded accepted limit, reaching 1543 lbs during impact. After impact the restraint buckle released with 8 lbs of force.

VDT6581- Cell I1, PV, CV-22, LARD, 15.06 G, 31.53 ft/s, 27.5 ms rise time
VDT6581 was a repeat of test VDT6579, with the exception of the subject substitution of the LARD manikin. Post-test examination indicated small stroke had occurred and the stroking mechanism appeared to be slightly loosened at the bottom connection point. Besides slight scarring to the inner stroking mechanism material and loosening of stoking rod, no structural damage was recorded. After impact the restraint buckle released with 8 lbs of force.

VDT6582- Cell J1, PV, CV-22, LARD, 32.10 G, 48.88 ft/s, 18.7 ms rise time
VDT6582 repeated the conditions of the previous test at a higher energy level. Damage to the seat fixture from the high level impact was fairly extensive. Outer stroking mechanism rods on both sides detached after maximum stroke was achieved. Seat stroke also resulted in the inner stroking material to become scarred upon impact, as well as subsequent denting to the back of the seat fixture. After impact the restraint buckle released with 7.5 lbs of force.

VDT6585- Cell A1, CV, CV-22, LOIS, 24.59 G, 40.56 ft/s, 35.4 ms rise time
VDT6585 was the first CV impact test performed in this program. Post-test examination indicated slight seat stroke had taken place, possibly loosening the outer stroking mechanism at the bottom connection point. Both peak lumbar Z and neck moment index X (UNMIx) exceeded accepted limits, reaching 1391 lbs and 0.5367, respectively. After impact the restraint buckle released with 21 lbs of force.

VDT6586- Cell B1, CV, CV-22, LOIS, 29.88 G, 48.82 ft/s, 18.9 ms rise time
VDT6586 reiterated test conditions in the previous test, VDT6585, but at a higher energy level. Seat stroked upon impact, causing scarring to the inner stroking mechanism material on both sides. Additional scarring was discovered during post-test inspection, located on the bottom left corner of the seat back due to the bulky piece at the bottom of the outer stroking mechanism. Peak lumbar Z exceeded accepted limit, reaching 1604 lbs during impact. After impact the restraint buckle released with 18 lbs of force.

VDT6587- Cell C1, CV, CV-22, LARD, 24.31 G, 40.47 ft/s, 25.2 ms rise time
VDT6587 was a repeat of test VDT6585, with the exception of the subject substitution of the LARD manikin. The seat did stroke upon impact, leaving the inner stroking mechanism material scarred on both sides of the seat. Also, while reviewing the high-speed video files for this test, it was discovered that due to the combined vertical configuration, the top of the outer stroking mechanism rod bent out during the end of the seat stroke. Denting to the seatback was also revealed during post-test examination. Both torso belt force and neck moment index X (UNMIx) exceeded accepted limits, reaching 2568 lbs and 1.3863, respectively. After impact the restraint buckle released with 35 lbs of force.

VDT6588- Cell D1, CV, CV-22, LARD, 29.71 G, 48.93 ft/s, 18.4 ms rise time
VDT6588 repeated the conditions of the previous test at a higher energy level. Damage to the seat fixture from the high level impact was fairly extensive. Seat stroke resulted in the inner stroking rod material and the surface on the side of the seat fixture to become scarred upon impact. The right outer stroking mechanism detached at the bottom connection point, while the inner stroking rod on the right was forced to bow out during stroke sequence. Subsequent denting and cracking to the back of the seat fixture was also discovered, as well as tethering to the left shoulder restraint. Torso belt force, neck moment index X (UNMIx), and neck moment index Z (UNMIz) exceeded accepted limits, reaching 2441 lbs, 1.7222, 0.5223, respectively. After impact the restraint buckle released with 38 lbs of force.

VDT6589- Cell A2, CV, CH-53, LOIS, 24.25 G, 40.51 ft/s, 32 ms rise time
VDT6589 was the first CV impact test performed with the CH-53 seat. Overall the seat showed no structural damage; however, the stroking mechanism material may have slightly been displaced, indicating seat stroke had occurred. All electronic data channels were present and continuous allowing data to be successfully collected. Peak lumbar Z exceeded accepted limit, reaching 2167 lbs during impact. After impact the restraint buckle released with 8 lbs of force.

VDT6590- Cell B2, CV, CH-53, LOIS, 29.96 G, 48.92 ft/s, 19.5 ms rise time
VDT6590 reiterated test conditions in the previous test, VDT6589, but at a higher energy level. Although this impact was of greater magnitude than the previous test, the seat still showed no structural damage post-impact. It was discovered the stroking mechanism material was more displaced after the stroke sequence than in the previous test. Both the chest resultant and peak lumbar Z exceeded accepted limits, reaching 64.34 G and 2522 lbs, respectively. After impact the restraint buckle released with 6 lbs of force.

VDT6591- Cell C2, CV, CH-53, LARD, 24.19 G, 40.51 ft/s, 20.9 ms rise time
VDT6591 was a repeat of test VDT6589, with the exception of the subject substitution of the LARD manikin. Overall the seat showed no structural damage; however, the stroking mechanism material may have slightly been displaced, indicating seat stroke had occurred. Both torso belt force and neck moment index X (UNMIx) exceeded accepted limits, reaching 2877 lbs and 0.6638, respectively. After impact the restraint buckle released with 12 lbs of force.

VDT6592- Cell D2, CV, CH-53, LARD, 30.11 G, 48.9 ft/s, 19.3 ms rise time
VDT6592 repeated the conditions of the previous test at a higher energy level. Seat stroke resulted in total displacement and minor chipping of the stroking mechanism material on both sides. Post-test inspection revealed movement or slight displacement of the piece connecting the seatback to the mounting portion of the seat; this piece also covers the stroking material, allowing sliding and stroke to occur. Subsequent denting and fracture discovered on the side of the seat pan, along with bending of the slanted seat pan support rod. Both torso belt force and neck moment index X (UNMIx) exceeded accepted limits, reaching 3375 lbs and 0.9153, respectively. After impact the restraint buckle released with 38 lbs of force.

VDT6593- Cell A, CV, Legacy H-60, LOIS, 24.33 G, 40.45 ft/s, 22.7 ms rise time
VDT6593 was the first test performed with the Legacy H-60 seat in the CV impact orientation. The seat did stroke at both top mount points and slightly at both seat legs. Overall the seat showed no structural damage; however, the middle restraint strap became tethered upon impact at the strap junction. Both peak lumbar Z and neck moment index X (UNMIx) exceeded accepted limits, reaching 1090 lbs and 0.5573, respectively. After impact the restraint buckle released with 20 lbs of force.

VDT6594- Cell B, CV, Legacy H-60, LOIS, 30.55 G, 48.57 ft/s, 19.1 ms rise time
VDT6594 reiterated test conditions in the previous test, VDT6593, but at a higher energy level. Shoulder restraints were unable to stay taut and hold the manikin in place during impact, leaving the manikin partially hunched over out of the seat. Main damage recorded during inspection was to the seat pan, where it was torn rather extensively on the left side. Both peak lumbar Z and neck moment index X (UNMIx) exceeded accepted limits, reaching 1130 lbs and 0.9575, respectively. After impact the restraint buckle released with 31 lbs of force.

VDT6595- Cell C, CV, Legacy H-60, LARD, 23.62 G, 40.45 ft/s, 21.3 ms rise time
VDT6595 was a repeat of test VDT6593, with the exception of the subject substitution of the LARD manikin. Once again, the rear retractor belt disengaged during impact, leaving the manikin hunched out of the seat. The top stroking mounts were more extended for this high energy impact. Tearing to the top of left strap that connects the seatback material to the rear of headrest was discovered; along with seam separation to the middle strap in the rear at the strap junction. Neck moment index X (UNMIx) exceeded accepted limit, reaching 0.7928 during impact. After impact the restraint buckle released with 22 lbs of force.

VDT6596- Cell C, CV, Legacy H-60, LARD, 24.52 G, 40.52 ft/s, 21.3 ms rise time
VDT6596 was a repeat of the previous test, VDT6595. Again, the rear retractor belt disengaged during impact, leaving the manikin hunched out of the seat. The top stroking mounts were more extended for this high energy impact. Tearing to the top of left strap that connects the seatback material to the rear of headrest was discovered; along with seam separation to the middle strap in the rear at the strap junction. Neck moment index X (UNMIx) exceeded accepted limit, reaching 0.5660 during impact. After impact the restraint buckle released with 28 lbs of force.

4.0 DISCUSSION

4.1 COMBINED VERTICAL TESTS

Peak torso belt forces, Chest Resultant G, peak lumbar Z force, DRZ, Nij, UNMIx, and UNMIz are reported for the CV orientation tests. Cells shown in red have exceeded the injury criteria.

Tables 7-8 show the injury comparison results for Cell A, a 24G shot with LOIS. As Table 7 indicates, all three seats exceeded the peak lumbar force limit of 965lbs. Table 8 summarizes the Nij neck injury data for Cell A. The CV-22 seat passed all the Nij criteria but failed to meet the Upper Neck Moment Index. The other two seats, CH-53 and H-60 did not pass either parameter.

Table 7. CV Cell A LOIS Injury Comparison Results

Test	Seat	Torso Belts Peak Force (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6585	CV-22	853	42.71	1391	33.44
VDT6589	CH-53	1207	53.34	2167	33.96
VDT6593	H-60	787	24.98	1090	29.79

Table 8. CV Cell A LOIS Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6585	CV-22	0.4477	0.2041	0.4271	0.2556	0.5367	0.2168
VDT6589	CH-53	0.4899	0.4188	0.9198	0.0529	0.1712	0.5223
VDT6593	H-60	0.5474	0.4337	0.2846	0.3569	0.5573	0.1786

Tables 9-10 show the injury comparison results for Cell B, a 30G shot with LOIS. As Table 9 indicates, all three seats exceeded the peak lumbar force limit of 965lbs and the CH-53 seat also exceeded the 60G limit for chest acceleration. Table 10 summarizes the Nij neck injury data for Cell B. All three seats failed the Nij criteria. In addition, the CV-22 and the H-60 failed the UNMIx criterion.

Table 9. CV Cell B LOIS Injury Comparison Results

Test	Seat	Torso Belts Peak Force (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6586	CV-22	1120	53.14	1604	38.48
VDT6590	CH-53	1575	64.34	2522	43.01
VDT6594	H-60	793	24.13	1130	33.69

Table 10. CV Cell B LOIS Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6586	CV-22	1.0207	0.2594	0.6168	0.1328	0.7779	0.2168
VDT6590	CH-53	0.6799	0.6185	0.9767	0.2567	0.2955	0.1815
VDT6594	H-60	0.7903	0.7956	0.345	0.2685	0.9575	0.2247

Tables 11-12 show the injury comparison results for Cell C, a 24G shot with LARD. As Table 11 indicates, the H-60 seat was the only one to not exceed the torso belt force limit of 2000lbs. None of the seats exceeded the 2232lb peak lumbar force limit. Table 12 summarizes the Nij neck injury data for Cell C. All three seats passed the Nij criteria but failed to meet the UNMIx criterion.

Table 11. CV Cell C LARD Injury Comparison Results

Test	Seat	Torso Belts Peak Force (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6587	CV-22	2568	40.93	940	22.19
VDT6591	CH-53	2877	38.21	1656	28.07
VDT6595	H-60	1131	18.3	840	18.66

Table 12. CV Cell C LARD Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6587	CV-22	0.4015	0.0934	0	0.209	1.3863	0.4906
VDT6591	CH-53	0.385	0.3063	0.2558	0.3755	0.6638	0.2026
VDT6595	H-60	0.2816	0	0.0672	0.2334	0.7928	0.1875

Tables 13-14 show the injury comparison results for Cell D, a 30G shot with LARD. As Table 13 indicates, the H-60 seat was the only one to not exceed the torso belt force limit of 2000lbs. None of the seats exceeded the 2232lb peak lumbar force limit. Table 14 summarizes the Nij neck injury data for Cell D. The CH-53 failed both the Nij criteria and the UNMIx criteria. The CV-22 and the H-60 both passed the Nij criteria but the CV-22 failed both UNMIx and UNMIz criteria while the H-60 failed the UNMIx criterion.

Table 13. CV Cell D LARD Injury Comparison Results

Test	Seat	Torso Belts Peak Force (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6588	CV-22	2441	42.26	1069	23.03
VDT6592	CH-53	3375	45.1	1470	21.91
VDT6596	H-60	1775	22.86	820	18.32

Table 14. CV Cell D LARD Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6588	CV-22	0.3829	0.1287	0.1959	0.2517	1.7222	0.5223
VDT6592	CH-53	0.5711	0.3631	0.1798	0.4199	0.9153	0.4294
VDT6596	H-60	0.4348	0.2151	0.073	0.1742	0.566	0.2634

4.2 PURE VERTICAL TESTS

Nij, peak lumbar Z force, peak chest acceleration resultant, peak torso belt force, and DRZ are reported for the Pure Vertical orientation. Cells shown in red have exceeded the injury criteria.

Tables 15-16 show the injury comparison results for Cell G, a 15G shot with LOIS. As Table 15 indicates, the CV-22 and the CH-53 exceeded the peak lumbar force limit of 965lbs. Table 16 summarizes the Nij neck injury data for Cell G. All seats passed the neck injury criteria.

Table 15. PV Cell G LOIS Injury Comparison Results

Test	Seat	Torso Belt Loads (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6571	H-60	5	19.18	823	23.88
VDT6575	CH-53	489	31.52	1368	25
VDT6579	CV-22	136	37.58	1102	27.85

Table 16. PV Cell G LOIS Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6571	H-60	0.0346	0.0136	0.103	0.135	0.1703	0.0483
VDT6575	CH-53	0.171	0	0.5072	0	0.0694	0.0489
VDT6579	CV-22	0.0332	0	0.4607	0.0155	0.0858	0.0383

Tables 17-18 show the injury comparison results for Cell H, a 34G shot with LOIS. As Table 17 indicates, all three seats exceeded the peak lumbar force parameter of 965lbs. Table 18 summarizes the Nij neck injury data for Cell H. Cells shown in red have exceeded the injury criteria. All seats failed the Nij criteria.

Table 17. Cell H LOIS Injury Comparison Results

Test	Seat	Torso Belt Loads (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6572	H-60	96	44.65	1353	36.72
VDT6576	CH-53	1102	59.23	2160	44.1
VDT6580	CV-22	723	43.85	1543	40.87

Table 18. PV Cell H LOIS Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6572	H-60	0.3241	0.3821	0.4135	0.6191	0.2849	0.0627
VDT6576	CH-53	0.4131	0	0.8154	0	0.1188	0.0562
VDT6580	CV-22	0.3803	0.1511	0.6719	0.0163	0.0692	0.0342

Tables 19-20 show the injury comparison results for Cell I, a 15G shot with LARD. There were no exceedances of any injury criteria during this cell.

Table 19. PV Cell I LARD Injury Comparison Results

Test	Seat	Torso Belt Loads (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6573	H-60	32	20.54	883	16.77
VDT6577	CH-53	656	15.67	1130	44.1
VDT6581	CV-22	474	16.42	1331	18.84

Table 20. PV Cell I LARD Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6573	H-60	0	0.0062	0.0993	0.212	0.2977	0.0524
VDT6577	CH-53	0.1125	0.0879	0.1616	0.271	0.0938	0.0357
VDT6581	CV-22	0.0786	0.028	0.0574	0.3111	0.041	0.0483

Tables 21-22 show the injury comparison results for Cell J, a 34G shot with LARD. The H-60 seat exceeded the UNMIx criteria. All other parameter limits were met by all seats.

Table 21. PV Cell J LARD Injury Comparison Results

Test	Seat	Torso Belt Loads (lbs)	Chest Resultant (G)	Peak Lumbar Force (lbs)	DRZ
VDT6574	H-60	253	52.16	1102	41.42
VDT6578	CH-53	837	40.09	1543	29.77
VDT6582	CV-22	1034	25.71	1678	29.86

Table 22. PV Cell J LARD Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6574	H-60	0.2084	0.0617	0.2752	0.3273	0.751	0.2515
VDT6578	CH-53	0.3766	0.123	0.2558	0.297	0.2112	0.1609
VDT6582	CV-22	0.0932	0.1202	0.4556	0.31	0.1591	0.0986

4.3 COMBINED HORIZONTAL TESTS

The CH orientation is primarily conducted to test the structural strength of each seat. Peak chest acceleration resultant, peak torso belt forces, and Nij are reported for the CH orientation. Since this was a structural test, LARD was utilized for all testing to simulate a worst case scenario. Cells shown in red have exceeded the injury criteria.

Tables 23-24 show the injury comparison results for Cell E, an 18G shot with LARD. As Table 23 indicates, the torso belt force limits were exceeded on the first H-60 test and on both the CV-22 and CH-53 tests. The H-60 seat was run at 18G's again due to complete failure of the restraint system and inertial reel which caused the manikin to be separated from the seat. The second test with the H-60 seat recorded smaller torso belt forces but again the restraint system and inertial reel failed as the manikin was separated from the seat. Therefore, although the torso belt loads did not exceed the limit, this is due to the fact that there was complete failure of the restraint system and the value was therefore flagged as a failure. The CV-22 and the CH-53 exceeded the torso belt loads but the seat and restraint systems remained together. There was collateral damage to the seats but not complete destruction as seen with the H-60. Table 24 summarizes the Nij neck injury data for Cell E. The H-60 data should not be discussed due to the fact that the seat failed and the manikin was separated from the seat during the event. This makes the Nij data collected inaccurate. The CV-22 exceeded both the Nij and UNMIx criteria. The CH-53 exceeded only the UNMIx criteria.

Table 23. CH Cell E LARD Injury Comparison Results

Test	Seat	Torso Belt Force (lbs)	Chest Resultant (G)
HIA8966	H-60	2891	17.91
HIA8967	H-60	1347	25.33
HIA8968	CV-22	5851	35.33
HIA8970	CH-53	4989	36.3

Table 24. CH Cell LARD Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
HIA8966	H-60	2.4664	2.5301	0	0.2506	0.3415	0.1028
HIA8967	H-60	2.5062	2.6135	0.0898	2.8389	0.4943	0.1628
HIA8968	CV-22	2.6852	2.5906	2.9637	2.7987	1.377	0.244
HIA8970	CH-53	0.4956	0.3148	0.023	0.0256	1.2657	0.1754

Tables 25-26 show the injury comparison results for Cell F, a 24G shot with LARD. There was massive structural failure of both seats during these tests and therefore the accuracy of the data collected is questionable.

Table 25. CH Cell F LARD Injury Comparison Results

Test	Seat	Torso Belt Force (lbs)	Chest Resultant (G)
HIA8969	CV-22	5257	40.97
HIA8971	CH-53	5644	50.42

Table 26. CH Cell LARD Neck Injury Comparison Results

Test	Seat	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
HIA8969	CV-22	2.5462	2.5157	2.7827	2.7755	1.0243	0.3816
HIA8971	CH-53	0.395	0.2228	0.0286	0.025	0.931	0.2331

5.0 SUMMARY

5.1 COMBINED VERTICAL TESTS

The injury comparison data for LOIS during the combined vertical tests showed that all the seats exceeded the peak lumbar load limit of 965lbs, the H-60 seat was at least 300lbs less than the other two seats. The neck injury criteria was exceeded by all three seats in at least one category of the Nij or UNMIxz during the low G tests and these exceedances got worse at the higher G-level. The CH-53 seat exceeded the chest acceleration resultant limit of 60G during the high G level test.

The injury comparison data for LARD during the combined vertical tests showed that the CV-22 and CH-53 seats exceeded the 2000lb torso belt limit on both tests while the H-60 seats passed this parameter. In fact, the H-60 torso belt force load was approximately 650lbs less than the next highest measurement. All seats failed the UNMIx value for both tests. The CV-22 exceeded the UNMIz at the high G level and the CH-53 exceeded the Ntf at the high G level.

Overall, the combined vertical tests showed that the H-60 seat had approximately a 25% chance of exceedance in one category while the CV-22 had a 31% and the CH-53 had a 36%. The tests also showed that the smaller occupant had a 16% higher rate of limit exceedance when compared to the large occupant. All seats had high DRZ values correlating to a high probability of lumbar injury during the impact.

5.2 PURE VERTICAL TESTS

The injury comparison data for LOIS during the pure vertical tests showed an exceedance of the peak lumbar force limit for the CV-22 and CH-53 seat at the low G level. All three seats exceeded this limit at the high G level test. All seats passed the neck injury criteria during the low G level tests. The CV-22 and CH-53 seat exceeded the Ncf limit during the high G test while the H-60 seat exceeded the Nce limit during this test. The H-60 seat consistently had the lowest DRZ value.

The injury comparison data for LARD during the pure vertical tests showed no injury criteria were exceeded during the low G tests. There was only one exceedance during the high G tests; the H-60 seat exceeded the UNMIx criteria.

Overall, the pure vertical tests showed that all seats provided identically the same occupant protection with an 8% chance of limit exceedance. Although there was still a higher incidence of criteria exceedance with the smaller occupant when compared to the large occupant, it was not nearly as pronounced as in the combined vertical tests.

5.3 COMBINED HORIZONTAL TESTS

The combined horizontal tests were structural in nature and designed to test the durability and structural integrity of the seats. The H-60 seats completely broke down during the tests. The seating restraint system completely failed and the inertial reels never engaged to protect the occupant. In both instances, the manikin separated from the seat on both low G tests and several manikin body parts were broken.

The CV-22 seat remained structurally intact at the low G level although we did see partial tearing in the lap belt. During the high G test, there was extensive damage to the seat and fixture. The seat fixture failed at both mounts and became detached from the sled and test structure.

The CH-53 seat had no visible structural damage at the low G level test and performed the best of the three seats. The seat fixture did show extensive damage at the High G test. There was complete fracture of both stroking rods causing the manikin to become partially dislodged from the seat in a hunched position.

Overall, the H-60 seat performed the worse structurally. A real concern arose with the test team since the seat restraint system completely failed and the inertial reel never engaged to protect the occupant. Problems identified during these H-60 tests raised serious questions about the integrity of the inertial reel system and occupant protection. The other two seats, the CV-22 and CH-53 performed well at the low G level. They both had complete structural failure at the high G level.

6.0 RECOMMENDATIONS

- Further testing of the reliability issues of the inertial reel in the existing H-60 seat noted during the structural tests of this program.
    - Emergently test inertial reels to find a satisfactory substitute for the reel currently deployed on the H-60 side facing seat.
- Helmets should be worn by all occupants in a rotorcraft.
- Adopt injury criteria to compare and acquire seats during rotorcraft and fixed wing aircraft acquisition programs.
- Consider application of the methodology developed in this program to quickly and inexpensively compare occupant protection across different seats and aircraft platforms.
- A study including a 50th percentile male occupant manikin utilizing this testing and data analysis should be completed to fill the data gap between the small (5th) and large (95th) manikin data sets.

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8.0 GLOSSARY

711HPW	711th Human Performance Wing
ACH	Advanced Combat Helmet
AFRL	Air Force Research Laboratory
AIS	Abbreviated Injury Scale
CH	Combined Horizontal
CRADA	Cooperative Research & Development Agreement
CV	Combined Vertical
DAS	Data Acquisition System
DTS	Diversified Technical Systems
DOT&E	Office of the Director, Operational Test & Evaluation
DRMO	Defense Reutilization and Marketing Offices
DRZ	Dynamic Response Index Z
DSOC	Defense Safety Oversight Council
FSC	Full Spectrum Crashworthiness
HB50	Hybrid III 50%ile manikin
HIA	Horizontal Impulse Accelerator
HIC	Head Injury Criterion
IST	Infoscitex Corporation
JSF	Joint Strike Fighter
LARD	Large Anthropomorphic Research Device
LOIS	Lightest Occupant In Service
MOA	Memorandum of Agreement
NIC	Neck Injury Criteria
OSD	Office of the Secretary of Defense
PV	Pure Vertical
RHCP	Applied Neuroscience Branch
SBIR	Small Business Innovative Research
UNMIx	Upper Neck Moment Index X
UNMIz	Upper Neck Moment Index Z
VDT	Vertical Deceleration Tower

APPENDIX A: INJURY CRITERIA RESULTS

Test Number	Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
HIA8966	E	CH	Legacy H-60	LARD	18.26	47.19	NO	2891	17.91			2.4664	2.5301	0.0000	0.2506	0.3415	0.1028	73
HIA8967	E	CH	Legacy H-60	LARD	18.05	46.93	NO	1347	25.33			2.5062	2.6135	0.0898	2.8389	0.4943	0.1628	76
HIA8968	E1	CH	CV-22	LARD	17.49	46.21	YES	5851	35.33			2.6852	2.5906	2.9637	2.7987	1.3770	0.2440	69
HIA8969	F1	CH	CV-22	LARD	24.36	53.02	NO	5257	40.97			2.5462	2.5157	2.7827	2.7755	1.0243	0.3816	62.3
HIA8970	E2	CH	CH-53	LARD	17.06	46.14	YES	4989	36.3			0.4956	0.3148	0.0230	0.0256	1.2657	0.1754	73.8
HIA8971	F2	CH	CH-53	LARD	23.7	52.63	NO	5644	50.42			0.3950	0.2228	0.0286	0.0250	0.9310	0.2331	57.7
VDT6571	G	PV	Legacy H-60	LOIS	14.95	31.2	YES	5	19.18	823	23.88	0.0346	0.0136	0.1030	0.1350	0.1703	0.0483	55.4
VDT6572	H	PV	Legacy H-60	LOIS	33.8	48.87	NO	96	44.65	1353	36.72	0.3241	0.3821	0.4135	0.6191	0.2849	0.0627	57
VDT6573	I	PV	Legacy H-60	LARD	15.42	31.72	YES	32	20.54	883	16.77	0.0000	0.0062	0.0993	0.2120	0.2997	0.0524	36.6
VDT6574	J	PV	Legacy H-60	LARD	35.43	48.94	NO	253	52.16	1102	41.42	0.2084	0.0617	0.2752	0.3273	0.7510	0.2515	33.2
VDT6575	G2	PV	CH-53	LOIS	14.82	31.16	YES	489	31.52	1368	25	0.1710	0.0000	0.5072	0.0000	0.0694	0.0489	24.9
VDT6576	H2	PV	CH-53	LOIS	32.55	48.97	YES	1102	59.23	2160	44.1	0.4131	0.0000	0.8154	0.0000	0.1188	0.0562	19.1
VDT6577	I2	PV	CH-53	LARD	14.84	31.39	YES	656	15.67	1130	20.68	0.1125	0.0879	0.1616	0.2710	0.0938	0.0357	27.5
VDT6578	J2	PV	CH-53	LARD	34.8	48.94	YES	837	40.09	1543	29.77	0.3766	0.1230	0.2558	0.2970	0.2112	0.1609	19.1
VDT6579	G1	PV	CV-22	LOIS	14.71	31.2	YES	136	37.58	1102	27.85	0.0332	0.0000	0.4607	0.0155	0.0858	0.0383	28.1
VDT6580	H1	PV	CV-22	LOIS	33.65	48.99	YES	723	43.85	1543	40.87	0.3803	0.1511	0.6719	0.0163	0.0692	0.0342	17.8
VDT6581	I1	PV	CV-22	LARD	15.06	31.53	YES	474	16.42	1331	18.84	0.0786	0.0280	0.0574	0.3111	0.0410	0.0483	27.5
VDT6582	J1	PV	CV-22	LARD	32.01	48.88	YES	1034	25.71	1678	29.86	0.0932	0.1202	0.4556	0.3100	0.1591	0.0986	18.7
VDT6585	A1	CV	CV-22	LOIS	24.59	40.56	YES	853	42.71	1391	33.44	0.4477	0.2041	0.4271	0.2556	0.5367	0.2168	35.4
VDT6586	B1	CV	CV-22	LOIS	29.88	48.82	YES	1120	53.14	1604	38.48	1.0207	0.2594	0.6168	0.1328	0.7779	0.2882	18.9
VDT6587	C1	CV	CV-22	LARD	24.31	40.47	YES	2568	40.93	940	22.19	0.4015	0.0934	0.0000	0.2090	1.3863	0.4906	25.2
VDT6588	D1	CV	CV-22	LARD	29.71	48.93	YES	2441	42.26	1069	23.03	0.3829	0.1287	0.1959	0.2517	1.7222	0.5223	18.4
VDT6589	A2	CV	CH-53	LOIS	24.25	40.51	YES	1207	53.34	2167	33.96	0.4899	0.4188	0.9198	0.0529	0.1712	0.1375	32
VDT6590	B2	CV	CH-53	LOIS	29.96	48.92	YES	1575	64.34	2522	43.01	0.6799	0.6185	0.9767	0.2567	0.2955	0.1815	19.5
VDT6591	C2	CV	CH-53	LARD	24.19	40.51	YES	2877	38.21	1656	28.07	0.3850	0.3063	0.2558	0.3775	0.6638	0.2026	20.9
VDT6592	D2	CV	CH-53	LARD	30.11	48.9	NO	3375	45.1	1470	21.91	0.5711	0.3631	0.1798	0.4199	0.9153	0.4294	19.3
VDT6593	A	CV	Legacy H-60	LOIS	24.33	40.45	YES	787	24.98	1090	29.79	0.5474	0.4337	0.2846	0.3569	0.5573	0.1786	22.7
VDT6594	B	CV	Legacy H-60	LOIS	30.55	48.57	NO	793	24.13	1130	33.69	0.7903	0.7956	0.3450	0.2685	0.9575	0.2247	19.1
VDT6595	C	CV	Legacy H-60	LARD	23.62	40.45	NO	1131	18.3	840	18.66	0.2816	0.0000	0.0672	0.2334	0.7928	0.1875	21.3
VDT6596	D	CV	Legacy H-60	LARD	24.52	40.52	NO	1775	22.86	820	18.32	0.4348	0.2151	0.0730	0.1742	0.5660	0.2634	21.3

APPENDIX B: H-60 INJURY CRITERIA ORGANIZED BY SEAT ORIENTATION

Test Number	Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
HIA8966	E	CH	egacy H-6	LARD	18.26	47.19	NO	2891	17.91			2.4664	2.5301	0.0000	0.2506	0.3415	0.1028	73
HIA8967	E	CH	egacy H-6	LARD	18.05	46.93	NO	1347	25.33			2.5062	2.6135	0.0898	2.8389	0.4943	0.1628	76

Test Number	Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
VDT6571	G	PV	egacy H-6	LOIS	14.95	31.2	YES	5	19.18	823	23.88	0.0346	0.0136	0.1030	0.1350	0.1703	0.0483	55.4
VDT6572	H	PV	egacy H-6	LOIS	33.8	48.87	NO	96	44.65	1353	36.72	0.3241	0.3821	0.4135	0.6191	0.2849	0.0627	57
VDT6573	I	PV	egacy H-6	LARD	15.42	31.72	YES	32	20.54	883	16.77	0.0000	0.0062	0.0993	0.2120	0.2997	0.0524	36.6
VDT6574	J	PV	egacy H-6	LARD	35.43	48.94	NO	253	52.16	1102	41.42	0.2084	0.0617	0.2752	0.3273	0.7510	0.2515	33.2

Test Number	Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
VDT6593	A	CV	egacy H-6	LOIS	24.33	40.45	YES	787	24.98	1090	29.79	0.5474	0.4337	0.2846	0.3569	0.5573	0.1786	22.7
VDT6594	B	CV	egacy H-6	LOIS	30.55	48.57	NO	793	24.13	1130	33.69	0.7903	0.7956	0.3450	0.2685	0.9575	0.2247	19.1
VDT6595	C	CV	egacy H-6	LARD	23.62	40.45	NO	1131	18.3	840	18.66	0.2816	0.0000	0.0672	0.2334	0.7928	0.1875	21.3
VDT6596	D	CV	egacy H-6	LARD	24.52	40.52	NO	1775	22.86	820	18.32	0.4348	0.2151	0.0730	0.1742	0.5660	0.2634	21.3

APPENDIX C: CV-22 INJURY CRITERIA ORGANIZED BY SEAT ORIENTATION

Test Number	Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
HIA8968	E1	CH	CV-22	LARD	17.49	46.21	YES	5851	35.33			2.6852	2.5906	2.9637	2.7987	1.3770	0.2440	69
HIA8969	F1	CH	CV-22	LARD	24.36	53.02	NO	5257	40.97			2.5462	2.5157	2.7827	2.7755	1.0243	0.3816	62.3

Test Number	Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
VDT6579	G1	PV	CV-22	LOIS	14.71	31.2	YES	136	37.58	1102	27.85	0.0332	0.0000	0.4607	0.0155	0.0858	0.0383	28.1
VDT6580	H1	PV	CV-22	LOIS	33.65	48.99	YES	723	43.85	1543	40.87	0.3803	0.1511	0.6719	0.0163	0.0692	0.0342	17.8
VDT6581	I1	PV	CV-22	LARD	15.06	31.53	YES	474	16.42	1331	18.84	0.0786	0.0280	0.0574	0.3111	0.0410	0.0483	27.5
VDT6582	J1	PV	CV-22	LARD	32.01	48.88	YES	1034	25.71	1678	29.86	0.0932	0.1202	0.4556	0.3100	0.1591	0.0986	18.7

Test Number	Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
VDT6585	A1	CV	CV-22	LOIS	24.59	40.56	YES	853	42.71	1391	33.44	0.4477	0.2041	0.4271	0.2556	0.5367	0.2168	35.4
VDT6586	B1	CV	CV-22	LOIS	29.88	48.82	YES	1120	53.14	1604	38.48	1.0207	0.2594	0.6168	0.1328	0.7779	0.2882	18.9
VDT6587	C1	CV	CV-22	LARD	24.31	40.47	YES	2568	40.93	940	22.19	0.4015	0.0934	0.0000	0.2090	1.3863	0.4906	25.2
VDT6588	D1	CV	CV-22	LARD	29.71	48.93	YES	2441	42.26	1069	23.03	0.3829	0.1287	0.1959	0.2517	1.7222	0.5223	18.4

APPENDIX D: CH-53 INJURY CRITERIA ORGANIZED BY SEAT ORIENTATION

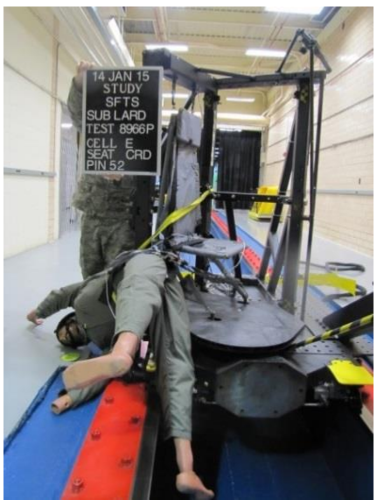
Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
E2	CH	CH-53	LARD	17.06	46.14	YES	4989	36.3			0.4956	0.3148	0.0230	0.0256	1.2657	0.1754	73.8
F2	CH	CH-53	LARD	23.7	52.63	NO	5644	50.42			0.3950	0.2228	0.0286	0.0250	0.9310	0.2331	57.7

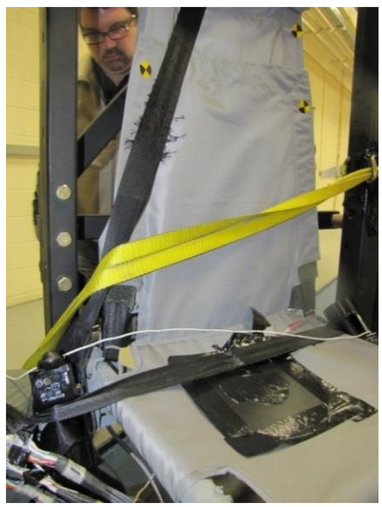
Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
G2	PV	CH-53	LOIS	14.82	31.16	YES	489	31.52	1368	25	0.1710	0.0000	0.5072	0.0000	0.0694	0.0489	24.9
H2	PV	CH-53	LOIS	32.55	48.97	YES	1102	59.23	2160	44.1	0.4131	0.0000	0.8154	0.0000	0.1188	0.0562	19.1
I2	PV	CH-53	LARD	14.84	31.39	YES	656	15.67	1130	20.68	0.1125	0.0879	0.1616	0.2710	0.0938	0.0357	27.5
J2	PV	CH-53	LARD	34.8	48.94	YES	837	40.09	1543	29.77	0.3766	0.1230	0.2558	0.2970	0.2112	0.1609	19.1

Test Cell	Orientation	Seat Type	Manikin Type	Peak Acceleration (G)	Velocity (ft/s)	Structure	Torso Belts Force (lb)	Chest Resultant (G)	Peak Lumbar Z (lb)	DRZ	Ntf	Nte	Ncf	Nce	MNIx	NMIz	Impact Rise Time (ms)
A2	CV	CH-53	LOIS	24.25	40.51	YES	1207	53.34	2167	33.96	0.4899	0.4188	0.9198	0.0529	0.1712	0.1375	32
B2	CV	CH-53	LOIS	29.96	48.92	YES	1575	64.34	2522	43.01	0.6799	0.6185	0.9767	0.2567	0.2955	0.1815	19.5
C2	CV	CH-53	LARD	24.19	40.51	YES	2877	38.21	1656	28.07	0.3850	0.3063	0.2558	0.3775	0.6638	0.2026	20.9
D2	CV	CH-53	LARD	30.11	48.9	NO	3375	45.1	1470	21.91	0.5711	0.3631	0.1798	0.4199	0.9153	0.4294	19.3

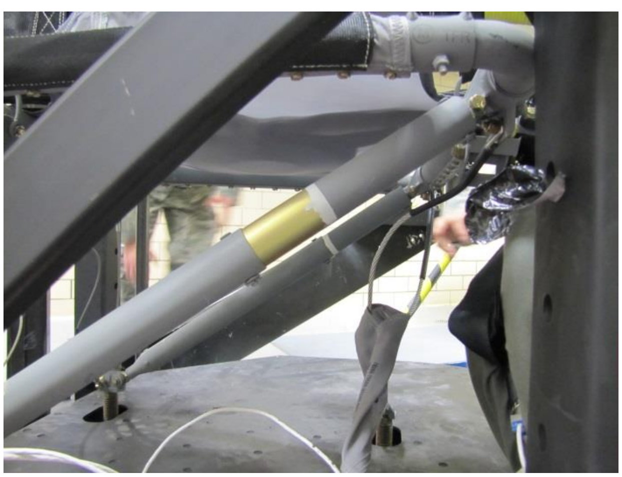
APPENDIX E: INDIVIDUAL TEST PICTURES

HIA8966- Cell E, CH, Legacy H-60, LARD, 18.26 G, 47.19 ft/s, 73 ms rise time

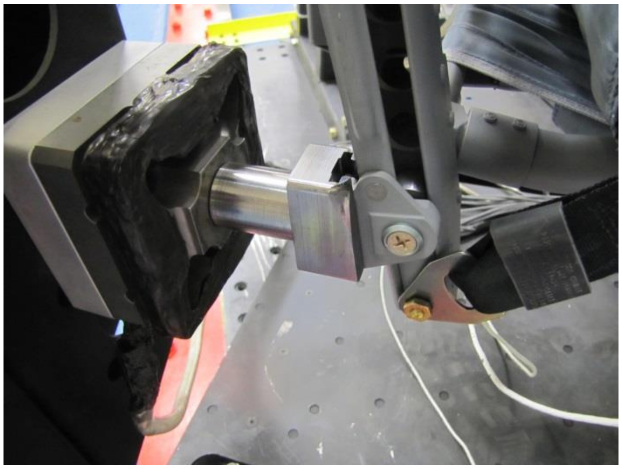




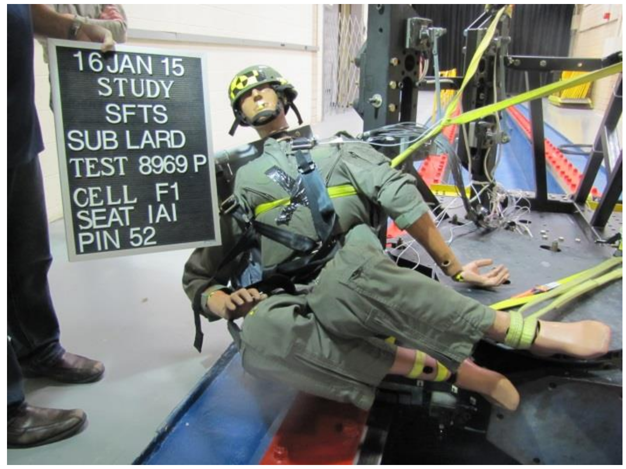
HIA8967- Cell E, CH, Legacy H-60, LARD, 18.05 G, 46.93 ft/s, 76 ms rise time

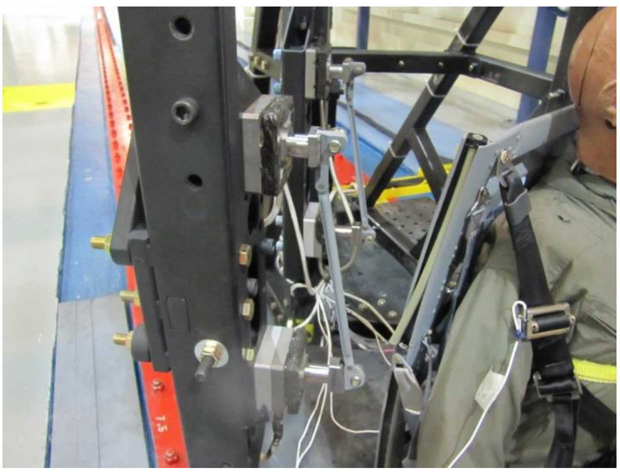


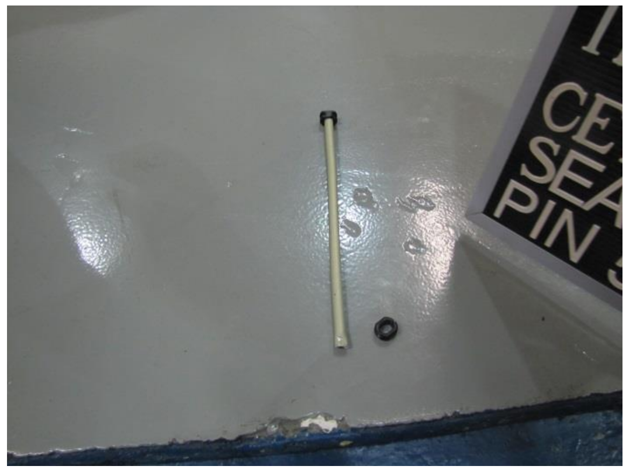
HIA8968- Cell E1, CH, CV-22, LARD, 17.49 G, 46.21 ft/s, 69 ms rise time

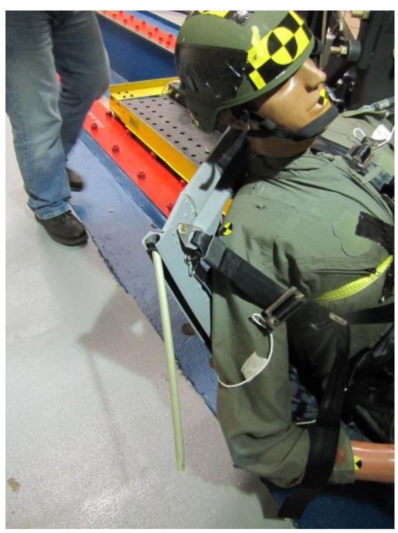


HIA8969- Cell F1, CH, CV-22, LARD, 24.36 G, 53.02 ft/s, 62.3 ms rise time

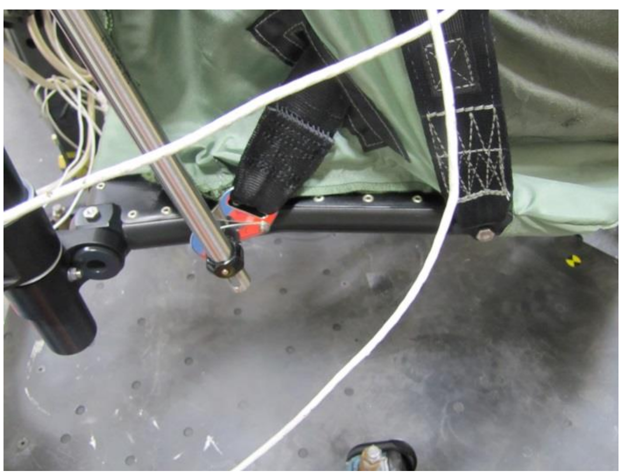






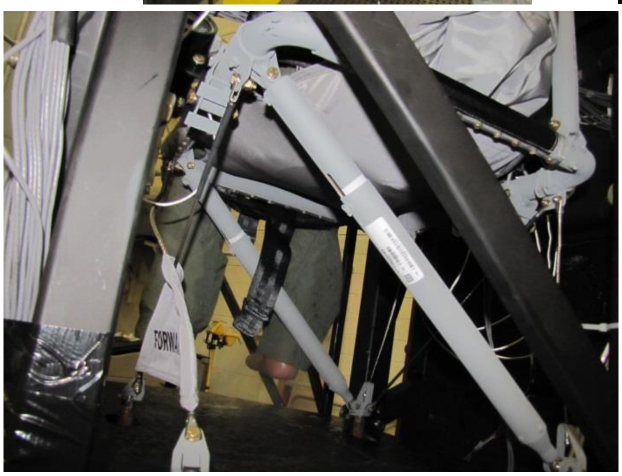


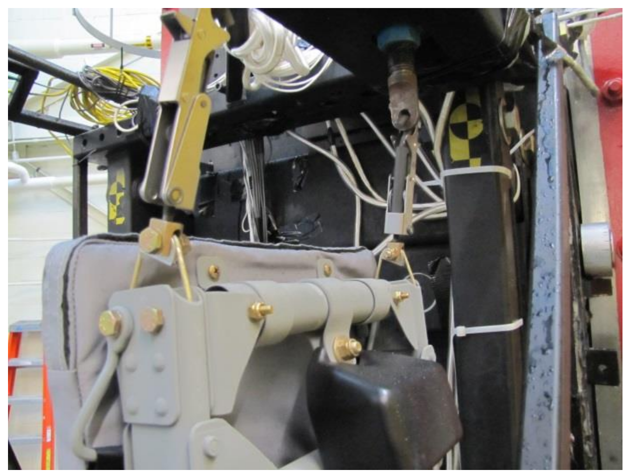
HIA8970- Cell E2, CH, CH-53, LARD, 17.06 G, 46.14 ft/s, 73.8 ms rise time



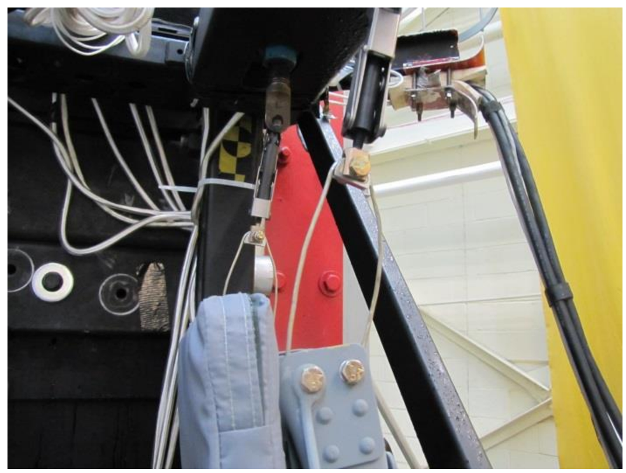
HIA8971- Cell F2, CH, CH-53, LARD, 23.7 G, 52.63 ft/s, 57.7 ms rise time

VDT6571- Cell G, PV, Legacy H-60, LOIS, 14.95 G, 31.2 ft/s, 55.4 ms rise time

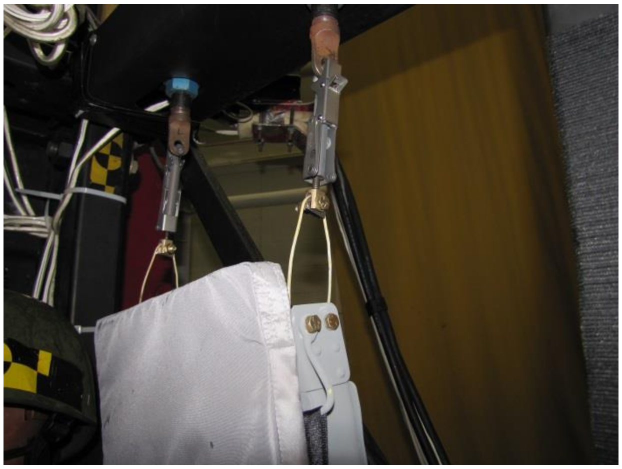




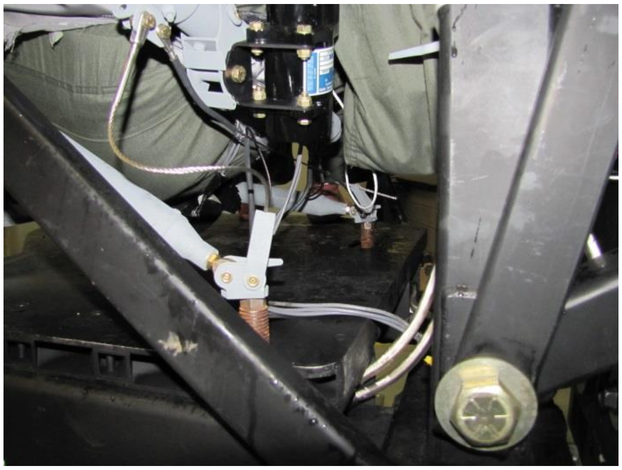
VDT6572- Cell H, PV, Legacy H-60, LOIS, 33.8 G, 48.87 ft/s, 57 ms rise time



VDT6573- Cell I, PV, Legacy H-60, LARD, 15.42 G, 31.72 ft/s, 36.6 ms rise time



VDT6574- Cell J, PV, Legacy H-60, LARD, 35.43 G, 48.94 ft/s, 33.2 ms rise time



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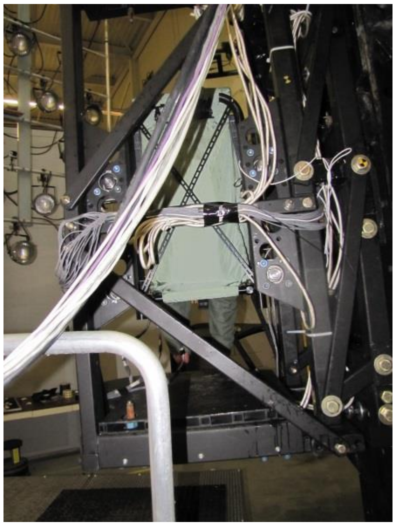
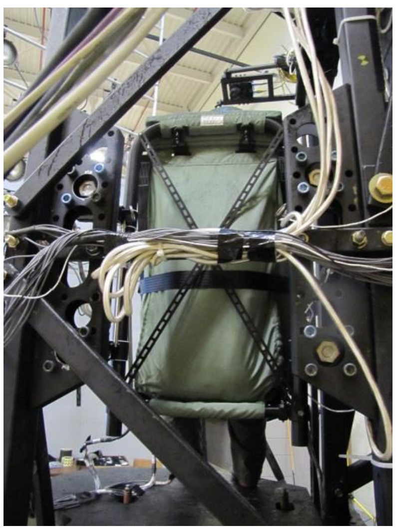
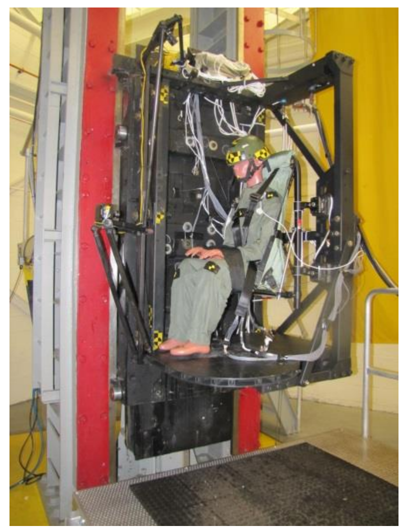
VDT6575- Cell G2, PV, CH-53, LOIS, 14.82 G, 31.16 ft/s, 24.9 ms rise time

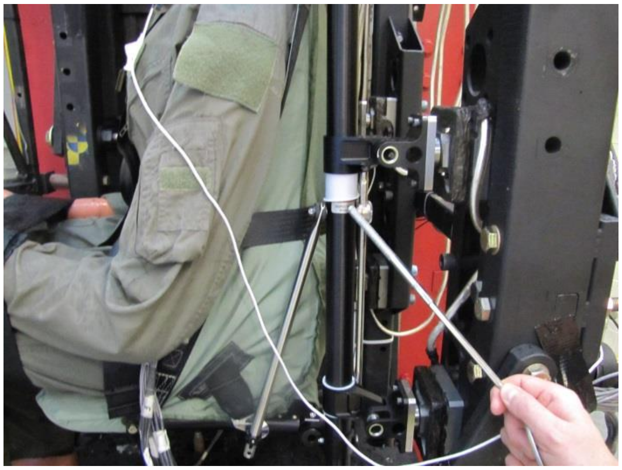


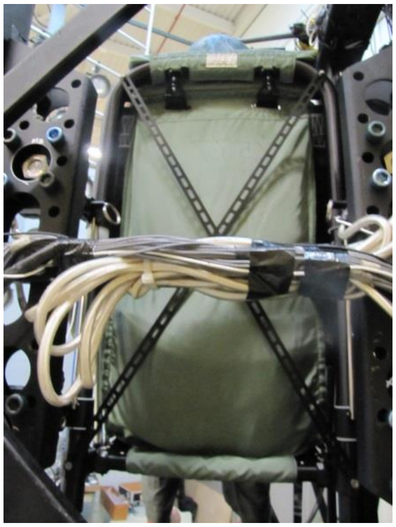
VDT6576- Cell H2, PV, CH-53, LOIS, 32.55 G, 48.97 ft/s, 19.1 ms rise time



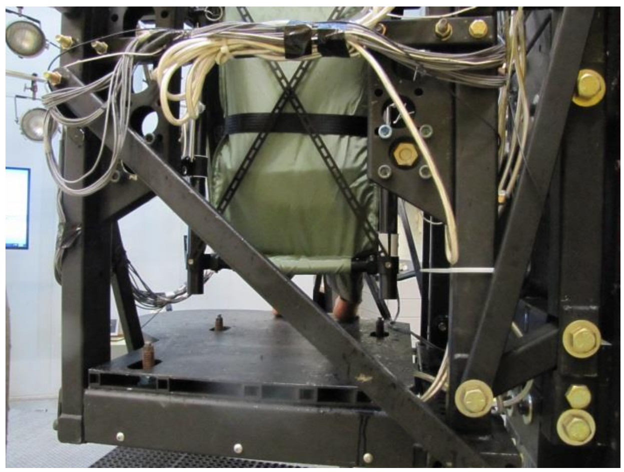


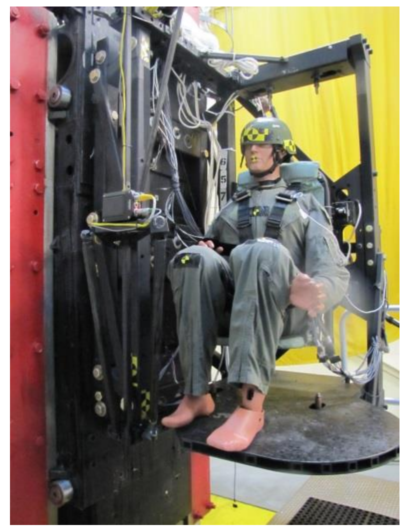
VDT6577- Cell I2, PV, CH-53, LARD, 14.34 G, 31.39 ft/s, 27.5 ms rise time



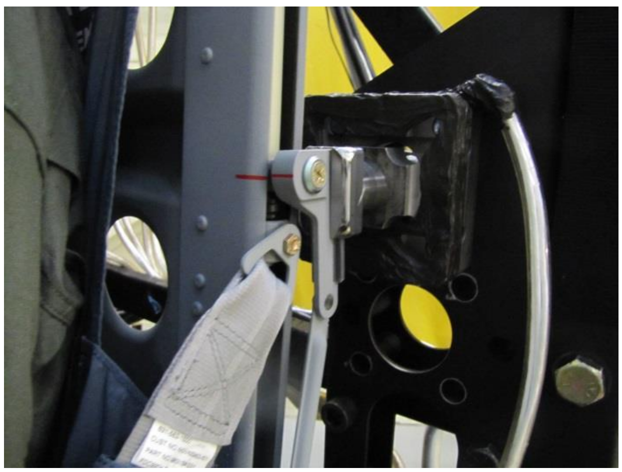


VDT6578- Cell J2, PV, CH-53, LARD, 34.8 G, 48.94 ft/s, 19.1 ms rise time





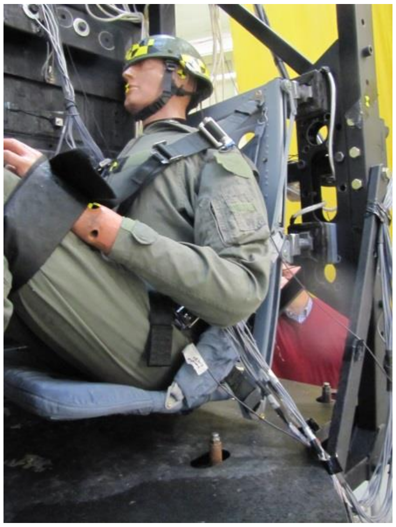
VDT6579- Cell G1, PV, CV-22, LOIS, 14.71 G, 31.2 ft/s, 28.1 ms rise time



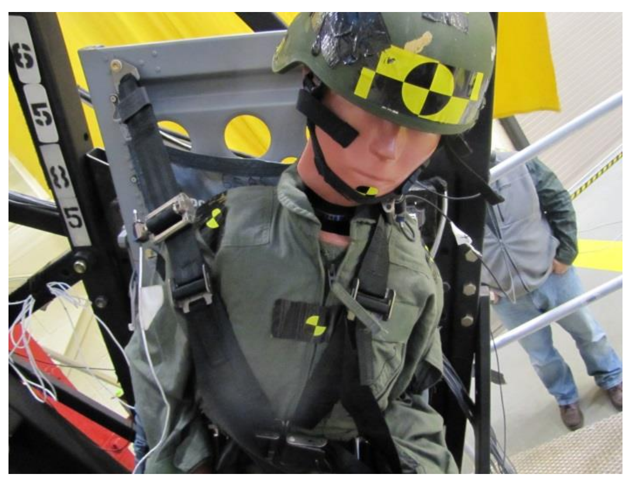
VDT6580- Cell H1, PV, CV-22, LOIS, 33.65 G, 48.99 ft/s, 17.8 ms rise time

VDT6581- Cell I1, PV, CV-22, LARD, 15.06 G, 31.53 ft/s, 27.5 ms rise time

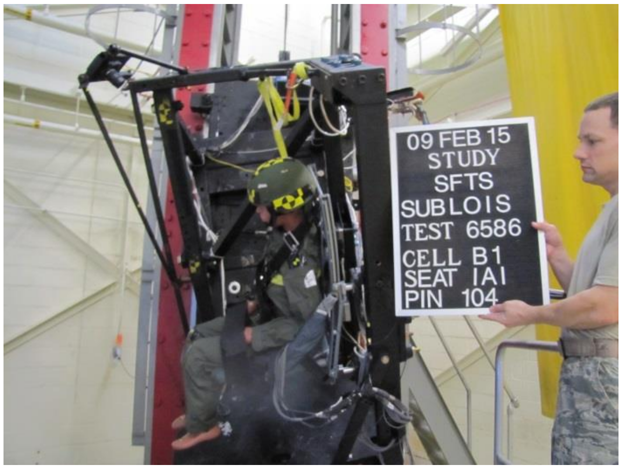
VDT6582- Cell J1, PV, CV-22, LARD, 32.10 G, 48.88 ft/s, 18.7 ms rise time

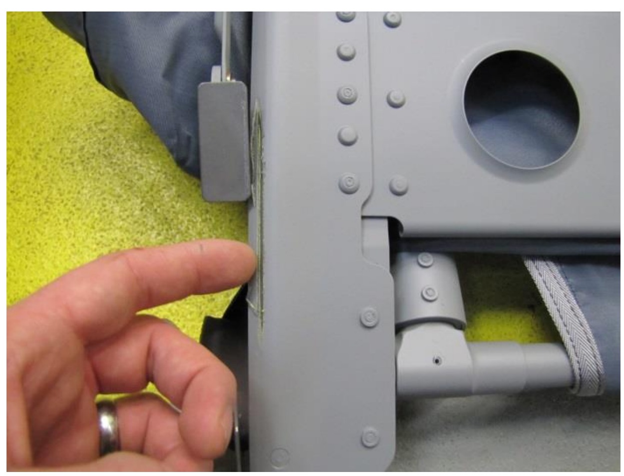


VDT6585- Cell A1, CV, CV-22, LOIS, 24.59 G, 40.56 ft/s, 35.4 ms rise time

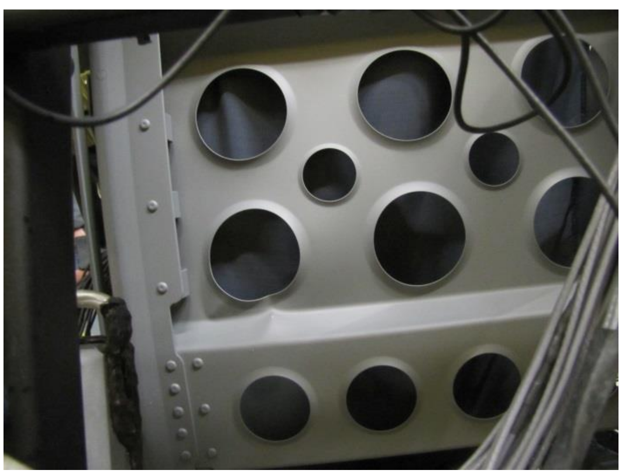


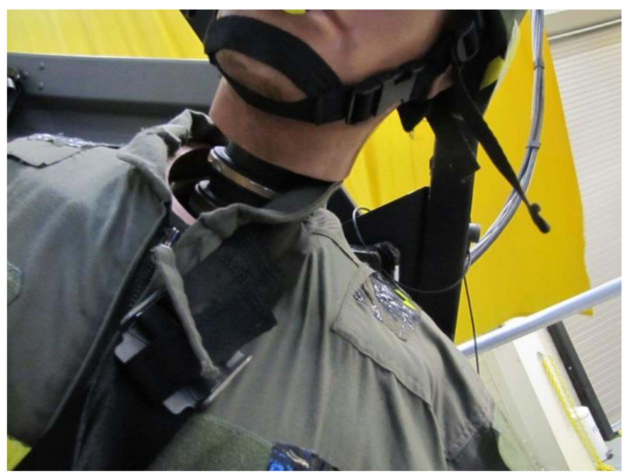
VDT6586- Cell B1, CV, CV-22, LOIS, 29.88 G, 48.82 ft/s, 18.9 ms rise time



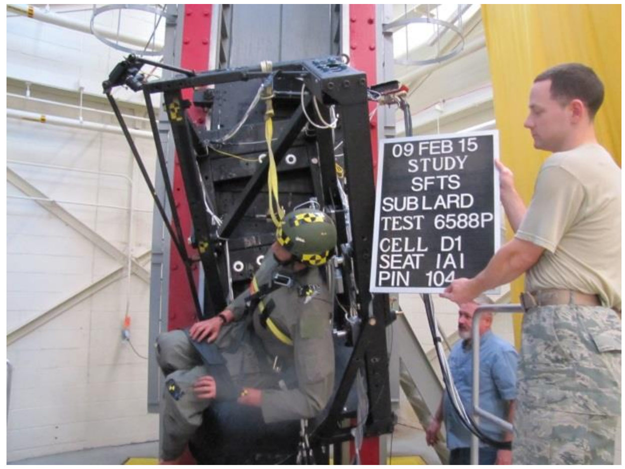


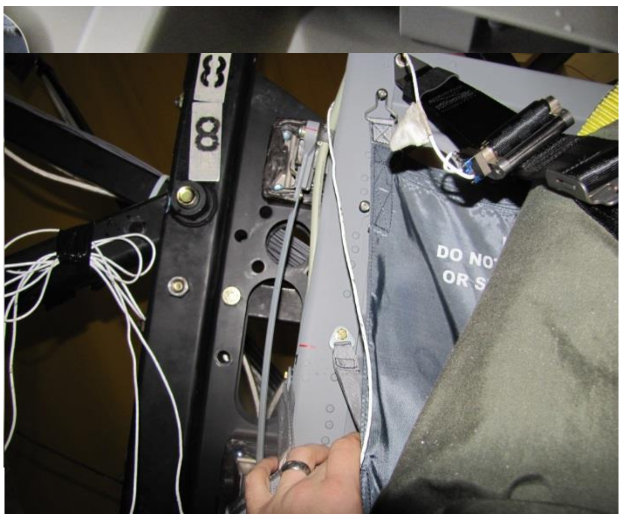
VDT6587- Cell C1, CV, CV-22, LARD, 24.31 G, 40.47 ft/s, 25.2 ms rise time

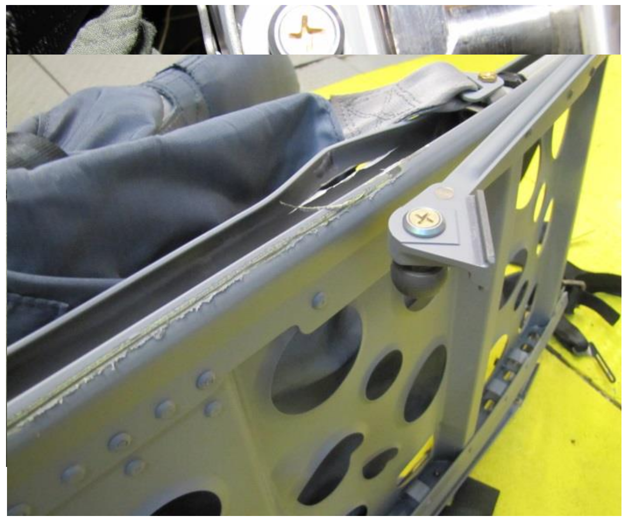




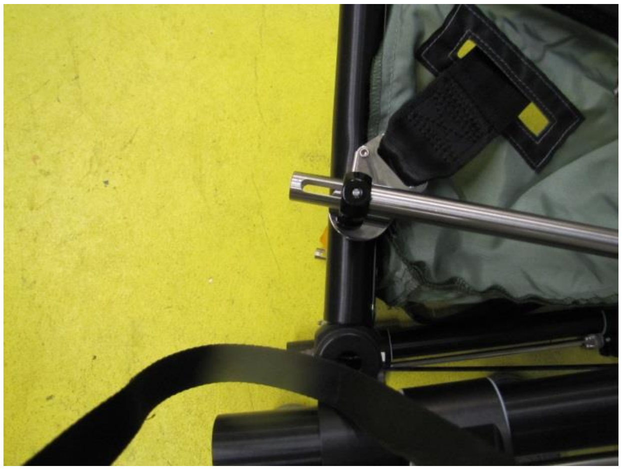
VDT6588- Cell D1, CV, CV-22, LARD, 29.71 G, 48.93 ft/s, 18.4 ms rise time



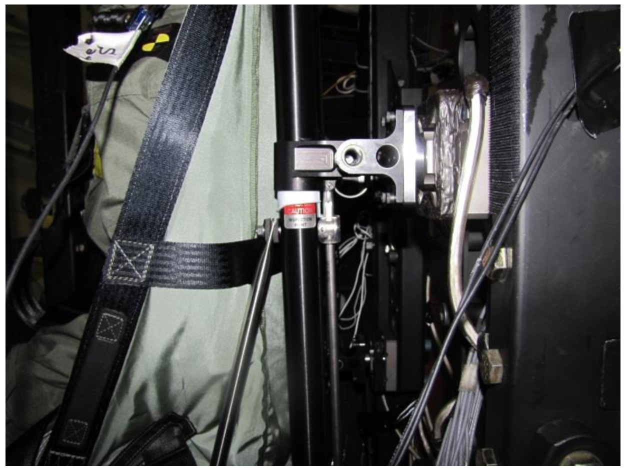




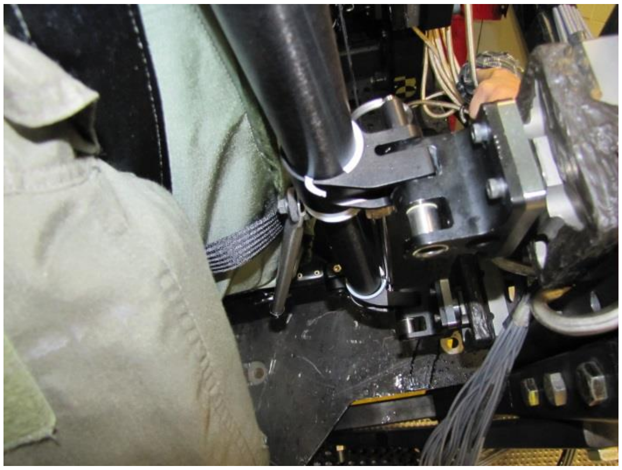
VDT6589- Cell A2, CV, CH-53, LOIS, 24.25 G, 40.51 ft/s, 32 ms rise time



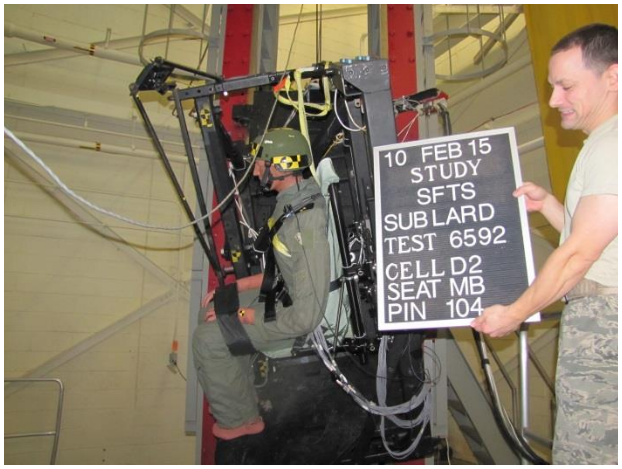
VDT6590- Cell B2, CV, CH-53, LOIS, 29.96 G, 48.92 ft/s, 19.5 ms rise time

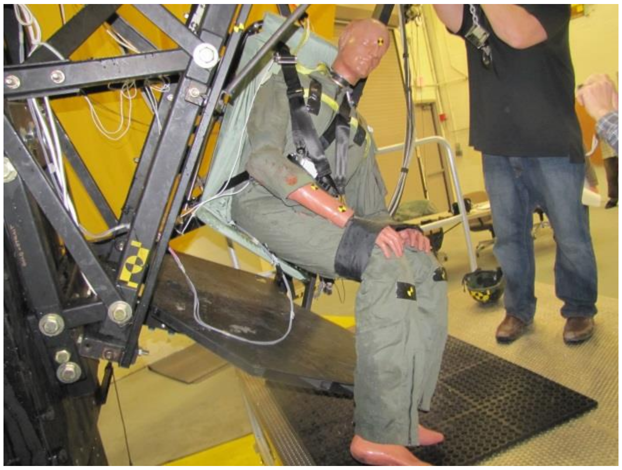


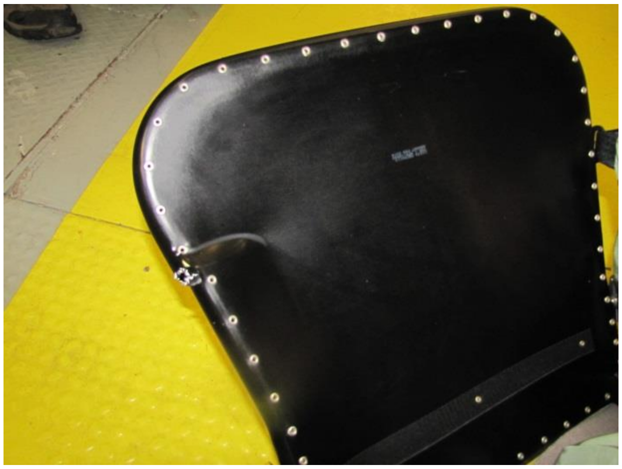
VDT6591- Cell C2, CV, CH-53, LARD, 24.19 G, 40.51 ft/s, 20.9 ms rise time



VDT6592- Cell D2, CV, CH-53, LARD, 30.11 G, 48.9 ft/s, 19.3 ms rise time

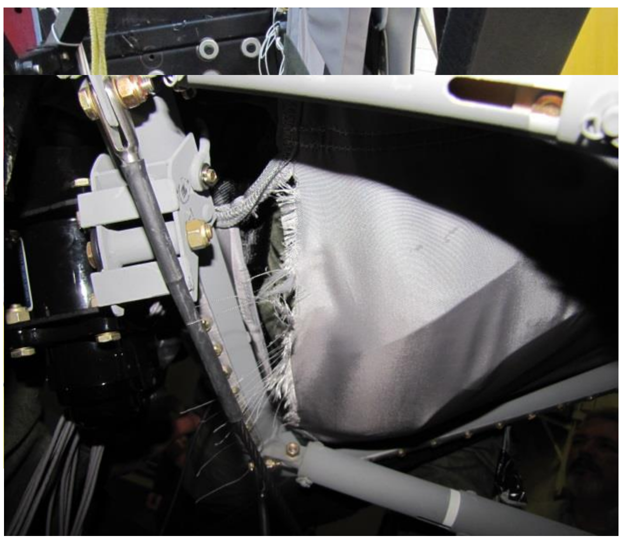




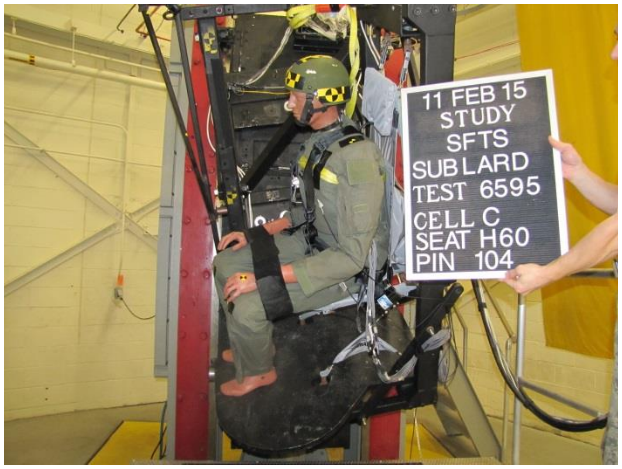


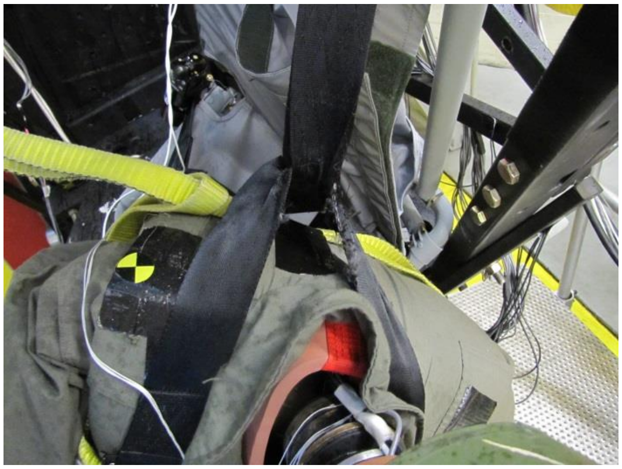
VDT6593- Cell A, CV, Legacy H-60, LOIS, 24.33 G, 40.45 ft/s, 22.7 ms rise time

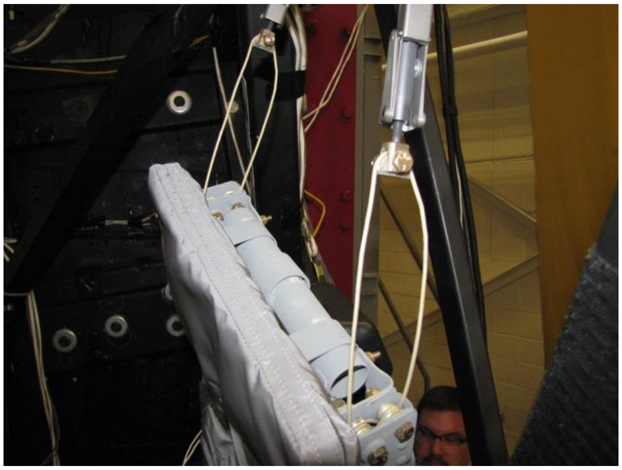
VDT6594- Cell B, CV, Legacy H-60, LOIS, 30.55 G, 48.57 ft/s, 19.1 ms rise time



VDT6595- Cell C, CV, Legacy H-60, LARD, 23.62 G, 40.45 ft/s, 21.3 ms rise time







VDT6596- Cell C, CV, Legacy H-60, LARD, 24.52 G, 40.52 ft/s, 21.3 ms